Human Systems Integration in Remotely Piloted Aircraft Operations

Anthony P. Tvaryanas

Tvaryanas AP. *Human systems integration in remotely piloted aircraft operations.* **Aviat Space Environ Med 2006; 77:1278–82.**

Background: The role of humans in remotely piloted aircraft (RPAs) is qualitatively different from manned aviation, lessening the applicability of aerospace medicine human factors knowledge derived from traditional cockpits. Aerospace medicine practitioners should expect to be challenged in addressing RPA crewmember performance. ***Methods:*** Human systems integration (HSI) provides a model for explaining human performance as a function of the domains of: human factors engineering; personnel; training; manpower; environment, safety, and occupational health (ESOH); habitability; and survivability. RPA crewmember performance is being particularly impacted by issues involving the domains of human factors engineering, personnel, training, manpower, ESOH, and habitability. ***Results:*** Specific HSI challenges include: 1) changes in large RPA operator selection and training; 2) human factors engineering deficiencies in current RPA ground control station design and their impact on human error including considerations pertaining to multi-aircraft control; and 3) the combined impact of manpower shortfalls, shiftwork-related fatigue, and degraded crewmember effectiveness. Limited experience and available research makes it difficult to qualitatively or quantitatively predict the collective impact of these issues on RPA crewmember performance. ***Conclusion:*** Attending to HSI will be critical for the success of current and future RPA crewmembers. Aerospace medicine practitioners working with RPA crewmembers should gain first-hand knowledge of their task environment while the larger aerospace medicine community needs to address the limited information available on RPA-related aerospace medicine human factors. In the meantime, aeromedical decisions will need to be made based on what is known about other aerospace occupations, realizing this knowledge may have only partial applicability.

Keywords: unmanned aerial vehicle, UAV, performance, human factors.

AEROSPACE MEDICINE human factors involves ensuring humans have both the physical and mental capacity to perform under conditions associated with aerospace operations. Interest in aerospace medicine human factors is resurging as rapid technological advances change the fundamental roles of humans, with the ramification that "the considerable base of human factors knowledge derived from cockpit experience may have limited applicability to future systems" (14, p. v). This point is perhaps best illustrated by the recent proliferation of remotely piloted aircraft (RPAs), also known as unmanned or uninhabited aerial vehicles (UAVs), in which the aircrew and their aircraft are no longer necessarily co-located. From an occupational medicine perspective, RPAs are the engineering control for such traditional aeromedical physical hazards as hypobarics, hypoxia, acceleration, vibration, thermal stress, and those forms of spatial disorientation associated with acceleration. Nevertheless, optimum human performance continues to be a necessary, albeit not sufficient, condition for the successful employment of these systems. As a class, RPAs have historically suffered mishap rates 1–2 orders of magnitude greater than those of manned aviation with various studies attributing 17–69% of these mishaps to human factors (11). Moreover, a recent U.S. Air Force (USAF) Scientific Advisory Board study identified poor human systems integration (HSI) as the leading driver of RPA mishaps (14). Given that RPA crewmember task environments differ significantly from the more familiar cockpit environment on which much of aerospace medicine research and clinical practice has been based, current aerospace medicine practitioners may find themselves challenged to address HSI issues underlying RPA crewmember performance.

Human Systems Integration

It is helpful to first clarify what we mean by HSI since many view it narrowly as the interface of the human and the machine, synonymous with human factors engineering and cockpit design. This view actually encompasses only a single domain within HSI. HSI is based on the understanding that people are the critical elements within systems and adopting a human-centric perspective of systems increases productivity and safety while decreasing costs. What HSI does is describe a process model for obtaining performance, and perhaps more importantly, identifies the action nodes for manipulating and thus optimizing performance (**Fig. 1**). Performance is a function of the quality of the inputs provided within the seven domains of HSI: human factors engineering (HFE); personnel; training; manpower; environment, safety, and occupational health (ESOH); habitability; and survivability. Since we all must function in a resource-constrained world, it is often not possible to ideally address each domain. Thus, the HSI model serves as a planning tool for program

From the 311[th] Human Systems Wing, Brooks City-Base, TX.

This manuscript was received for review in December 2005. It was accepted for publication in August 2006.

Address reprint requests to: Anthony P. Tvaryanas, M.D., M.P.H., MTM, who is Chief, Unmanned Aircraft System Human Systems Integration Branch, 311[th] Performance Enhancement Directorate, U.S. Air Force, 311 HSW/PER, 2485 Gillingham Drive, Brooks City-Base, TX 78235-5105; anthony.tvaryanas@brooks.af.mil.

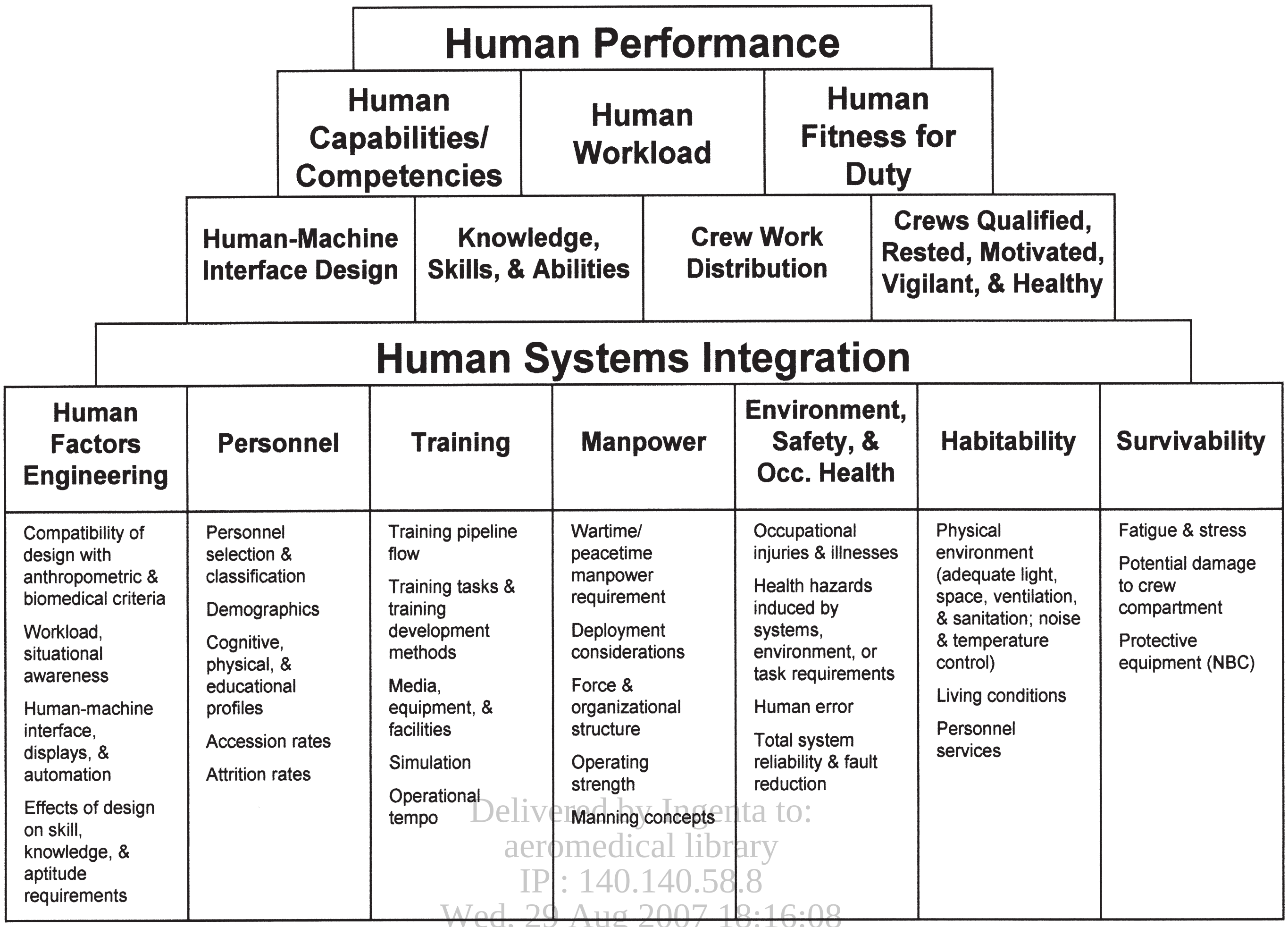

Fig. 1. Process model for obtaining human performance from the domains of human systems integration (HSI) with examples of HSI elements/areas of concern for each domain.

managers, allowing them to counter shortfalls in one domain by augmenting another. For example, a program forced to accept shortfalls in cockpit design (HFE domain) could respond by augmenting training (training domain) or selecting more capable or experienced aircrew (personnel domain). In addition, by providing an understanding of the underlying structure ("the anatomy") and processes ("the physiology") of human performance within complex systems, the HSI model has utility for clinically oriented aerospace medicine practitioners responsible for anticipating or diagnosing degraded performance. Such practitioners may use the HSI model to screen complex aerospace systems, such as an air traffic control center or a major weapons system, for subclinical pathology at the level of the individual HSI domains (e.g., a HSI gap analysis) in order to focus their interventions. This concept is synergistic with efforts by the Department of Defense's safety communities to employ the Human Factors Analysis and Classification System (HFACS) to identify "resident pathogens" within organizational and technical systems which can increase the likelihood for future mishaps.

As demonstrated in a recent study (12) of RPA mishaps linking HFACS categories to HSI domains, all HSI domains are pertinent to RPA crewmember performance. However, there may be differences in the relative importance of individual aerospace medicine human factors concerns for RPA vs. manned aircraft crewmembers (**Table I**). Our goal then is to introduce aerospace medicine practitioners to some of the HSI domain highlights underlying RPA crewmember performance. While it is not reasonable to expect aerospace medicine practitioners to be experts in all these domains, they need to have a working knowledge of the main issues in order to fully understand the task environment and human performance challenges. This is of immediate relevance because current military aerospace medicine practitioners can be expected to make aeromedical dispositions on RPA crewmembers, participate in RPA-focused aeromedical education and training programs, advise RPA squadron leadership on crew performance issues, and provide human factors consultation as members of RPA mishap investigation teams. Additionally, it is not unreasonable to expect that civil aeromedical examiners will be seeing RPA crewmembers in their clinical practices in the near future.

Personnel and Training Domains

One of the biggest changes in large RPAs involves the personnel and training domains and current efforts to develop a new career field for USAF RPA operators. The proposed training pipeline will start with new officer ac-

TABLE I. COMPARISON OF AEROSPACE MEDICINE HUMAN FACTORS CONCERNS FOR MANNED AIRCRAFT (MA) VERSUS REMOTELY PILOTED AIRCRAFT (RPA) CREWMEMBER PERFORMANCE.

Factors	MA	RPA†	Factors	MA	RPA†
Physical environment	+	+	Motion sickness	+	±
Vision restricted (clouds, ice, etc.)	+	+	Hypoxia & hypobarics	+	0
Noise & vibration	+	±	Visual adaptation	+	±
Windblast	+	0	Physical task oversaturation	+	+
Thermal stress	+	±			
Maneuvering forces	+	0	Perceptual factors	+	+
			Illusion - kinesthetic	+	0
Technological environment	+	+	Illusion - vestibular	+	0
Seating & restraints	+	0	Illusion - visual	+	+
Instrumentation	+	+	Misperception of operational conditions	+	+
Visibility restrictions (e.g., FOV)	±	+	Misinterpreted/misread instrument	+	+
Controls & switches	+	+	Spatial disorientation	+	+
Automation	+	+	Temporal distortion	+	+
Personal equipment	+	0			
Cognitive	+	+			
Vigilance & attention management	+	+	Crew coordination & communication	+	+
Cognitive task oversaturation	+	+	Distributed/virtual crew	0	±
Confusion	+	+	Shift changeovers	0	±
Negative transfer	+	+			
Distraction	+	+			
Geographic misorientation (lost)	+	+	Self-imposed stress	+	+
Checklist interference	+	+	Physical fitness	+	+
			Alcohol	+	+
Psycho-behavioral	+	+	Drugs, supplements, or self-medication	+	+
Personality style or disorder	+	+	Inadequate rest	+	+
Emotional state	+	+	Unreported disqualifying medical condition	+	+
Overconfidence	+	+			
Complacency	+	+			
Motivation	+	+			
Burnout	+	+	Miscellaneous		
			Multi-aircraft control	0	±
Adverse physiological states	+	+	Control & feedback latency	0	+
Effects of G-forces	±	0	Standardized cockpit design & controls	+	0
Prescribed drugs	+	+	Manual control of aircraft	+	±
Sudden incapacitation	+	+	Standardized crew qualifications	+	0
Pre-existing illness or injury	+	+	"Shared fate" with aircraft	+	0
Physical fatigue	+	+			
Mental fatigue	+	+			
Circadian desynchrony	+	+			

+ = usually applicable, ± = possibly applicable, 0 = not applicable.
† If an RPA is operated from another airborne platform, all MA performance concerns would also apply.

cessions and involve significantly less manned flight training when compared with the current practice of using experienced military pilots and navigators. This has obvious performance implications given the changes in scope of training and initial experience level. However, the impact of these changes is difficult to predict because of the limited number of well-designed studies (7,16) addressing necessary prerequisite knowledge, skills, and abilities, and conflicting findings and expert opinion regarding the value of prior manned aircraft flying experience (1,4,7,18). Additionally, current selection and aeromedical accession and certification processes will need to be evaluated for their partial or total applicability to this new career field. There currently are no uniform standards across the military services (16), nor are there formal civil standards for the aeromedical certification of RPA operators (18). While various organizations are developing recommendations for standards [American Society for Testing and Materials subcommittee F-38.03; National Aeronautics and Space Administration's Access 5 program (inactive); RTCA, Incorporated special committee 203; and SAE International's G-10 Aerospace Behavioral Engineering Technology Committee], there have been few studies (3) addressing medical standards based on an empirical analysis of the RPA operator task environment and there is little data to guide liberalizing current standards in order to address aeromedical accommodation (18).

Human Factors Engineering Domain

The RPA crew is unique compared with traditional aircrew since their task environment is the ground control station (GCS) rather than the cockpit. They often lack peripheral visual, auditory, and haptic cueing and are, therefore, relatively sensory deprived. They are nearly entirely dependent on focal vision in order to obtain information on vehicle state through either automation and displays or direct visual contact. This effectively limits the crew to the use of the central 30° of their visual field and requires them to process information using a neurosensory pathway not naturally adapted to providing primary spatial orientation cues. The effect of this sensory deprivation has not been well researched and little is known where RPA crewmembers direct their attentional focus or what information they use. For instance, a study (8) of visual scan patterns using the MQ-1 Predator head-up display revealed nonstandard instrument scan patterns with no adjustment to compensate for the lack of auditory or haptic cueing of engine performance. Additionally, a review (11) of RPA mishaps found human machine interface design and crewmember attentional factors were frequent causes of crew-related errors.

Advances in automation are decreasing the need for RPA pilots to have traditional pilot skills and instead emphasize monitoring and collaborative decision-making skills. However, the role of passive monitor makes maintaining a constant level of alertness exceedingly difficult and predisposes to "hazardous states of awareness"(6, p. 449). This was demonstrated in a study (9) of USAF RPA crewmembers which found high levels of subjective boredom and significant decrements in vigilance performance over the course of a single 8-h shift. Likewise, a study (2) of Army RPA pilots demonstrated degraded target detection and recognition performance as well as longer reaction times during nocturnal operations involving long flights. Although one of the best ways to overcome these effects is work breaks, there is concern for an acute decrement in crew situational awareness when control is transferred to another crew not currently involved in the mission. For example, the aforementioned Army RPA pilots preferred longer over shorter rotations because of the perception that longer rotations allowed for better situational awareness of the tactical environment (2). This is consistent with findings from other occupational domains such as air traffic control and even medicine, where patient transfers or handoffs were found to be one of the largest sources of medical errors.

Perhaps most unique of RPA operations is multi-aircraft control (MAC), where a crew controls more than one aircraft. For example, the recently fielded MQ-1 Predator MAC GCS provides the capability for one pilot and four sensor operators to control a maximum of four aircraft. The impact of transforming the role of the RPA operator from single pilot to multiple systems manager on skill, knowledge, and aptitude requirements is currently unknown. A review (5) of the human factors literature on RPAs concluded there is only limited research suggesting one operator may control more than one RPA under relatively idealized conditions including closely coordinated and correlated activities, a stable environment, and reliable automation. Other research (17) has demonstrated operator performance controlling even a single RPA is significantly degraded when heavy demands are imposed by payload operations. This would suggest the ability of an operator to attend to multiple aircraft may be severely compromised under non-idealized conditions, especially if an aircraft is malfunctioning or damaged. MAC also introduces new considerations into aeromedical certification and accommodation decisions. First, the risk for impaired operator performance must now be weighed against the potential impact on multiple missions rather than a single mission. Second, MAC allows pilots to delegate limited aircraft control to "non-pilot" crewmembers, thus causing their duties to encroach on traditional pilot tasks (**Fig. 2**). Finally, there is no data to suggest the necessity or method for adjusting current hours-of-service rules for MAC operations.

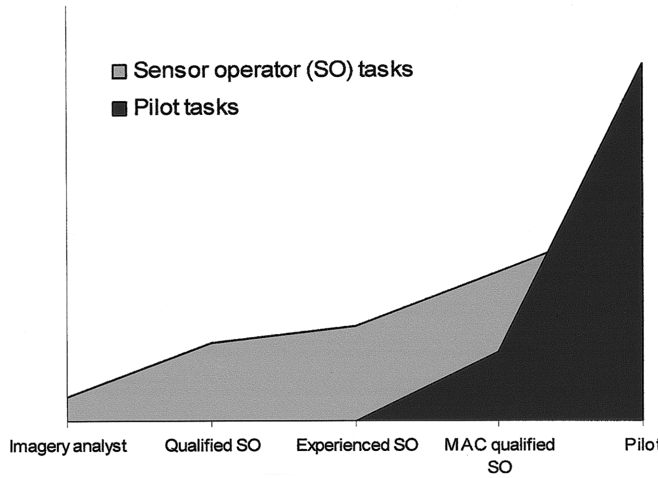

Fig. 2. Notional graph showing the trend for sensor operator duties to encroach on traditional pilot tasks as their mission participation and responsibilities increase in the multi-aircraft control (MAC) environment.

ESOH, Habitability, and Manpower Domains

The USAF's strategic vision for RPAs suggests "the absence of on-board aircrew mitigates the historic limitations of aircrew fatigue" (13, p. 5) in RPA operations. However, the introduction of long-endurance RPAs has necessitated the implementation of shift work for RPA crewmembers in order to provide the necessary around-the-clock staffing of GCSs. Serious public health concerns have been raised regarding the association between the documented effects of shift work and resulting degraded work performance with accompanying increased risk for errors and accidents. These concerns were validated by a recent study (10), which found higher reported fatigue levels among USAF RPA crewmembers as compared with traditional aircrew. Despite the potential for fatigue to be highly prevalent in RPA operations, only limited research has been conducted on the effects of fatigue on RPA operator error or its impact on operational efficiency. A simulation modeling study (15) analyzing the effects of fatigue, crew size, and rotation schedule on Army RPA crew workload and performance predicted almost three times as many mishaps could occur when a crew was fatigued as compared with rested. Although the results of the former study have not been operationally validated, an observational field study (9) of USAF RPA operators involved in rotational shift work noted decrements in mood, cognitive and piloting performance, and alertness associated with the acute fatigue of a single shift. This same study also found no association between hours-of-service rules for flying and reported acute or chronic fatigue.

Walters et al. notes operational requirements for RPA crewmembers "may include extended duty days, reduced crew size, and varying shift schedules" which are "likely to reduce operator effectiveness because of fatigue" (15, p. 13). Restated from an HSI perspective, RPA crewmember performance is at risk because of multiple, potentially synergistic domain shortfalls involving manpower (extended duty days and reduced crew size), habitability (fatigue), and ESOH (reduced operator effectiveness). Additionally, the HFE domain can be added to this mix when the design of the human-machine interface drives human error or inefficiency. Taken together, aerospace medicine practitioners should anticipate baseline degraded performance in RPA crewmembers, which is an important consideration when recommending performance interventions or consulting on mishap investigations. Additionally, aerospace medicine practitioners should recognize the RPA crewmember's work environment is potentially stressful, increasing the likelihood for exacerbations of underlying clinical or psychological conditions. In particular, the adverse chronobiological effects of sustained rotational shift work are an important consideration when making aeromedical accommodation decisions.

Conclusions

This is an exciting time for those directly involved with or supporting civil and military aerospace operations given the advent of an entirely new aerospace occupation, the RPA crewmember. For aerospace medicine practitioners, there are significant and immediate challenges and opportunities in addressing current and forecasting future aeromedical needs for this novel and rapidly growing career field. While technology can simplify the operation of individual RPAs, it is also increasing the span of control of individual operators and in the end may create task environments that are much more complex than those seen in traditional aviation. Thus, the trend is for technology to enhance rather than diminish the role of the human operator in "unmanned" aviation. As such, attending to HSI is critical for the success of current and future RPA crewmembers. No different from traditional aircrew, it is the responsibility of aerospace medicine practitioners to function as advocates for RPA crewmembers by using our specialty's knowledge to help optimize human performance. Since a fundamental precept in the practice of occupational medicine is the necessity of the work place visit, it is important for aerospace medicine practitioners to directly observe and participate in RPA operations. This is especially true for RPAs since the diversity of GCS designs prohibits generalizations about RPA task environments based on knowledge gained from an individual RPA. It is also important for the aerospace medicine community at large to diligently work to expand our knowledge of RPA-related aerospace medicine human factors so evidence-based recommendations and interventions can be made when we are challenged to address RPA crewmember performance. In the meantime, many aeromedical decisions will need to be made based on what is already known about other aerospace occupations, realizing this knowledge may have only partial applicability to the novel and varied task environments of RPA crewmembers.

ACKNOWLEDGMENTS

The views and opinions are those of the author and do not necessarily represent the views of the U.S. Air Force, the Department of Defense, or any other government agency.

REFERENCES

1. Barnes MJ, Knapp BG, Tillman BW, et al. Crew systems analysis of unmanned aerial vehicle (UAV) future job and tasking environments. Aberdeen Proving Ground, MD: Army Research Laboratory; 2000. Report No.: ARL-TR-2081.
2. Barnes MJ, Matz MF. Crew simulations for unmanned aerial vehicle (UAV) applications: sustained effects, shift factors, interface issues, and crew size. Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting; 1998 Oct; 5–9; Chicago, IL. Santa Monica, CA: Human Factors and Ergonomics Society; 1998.
3. Biggerstaff S, Blower DJ, Portman CA, et al. The development and initial validation of the unmanned aerial vehicle (UAV) external pilot selection system. Pensacola, FL: Naval Aerospace Medical Research Laboratory; 1998. Report No.: NAMRL-1398.
4. Hall EM, Tirre WC. USAF air vehicle operator training requirements study. Mesa, AZ: Air Force Research Laboratory; 1998. Report No.: AFRL-HE-BR-SR-1998–0001.
5. McCarley JS, Wickens CD. Human factors implications of UAVs in the national airspace. Atlantic City, NJ: Federal Aviation Administration, Department of Transportation; 2005. Report No.: AHFD-05–05/FAA-05–01.
6. Pope AT, Bogart EH. Identification of hazardous awareness states in monitoring environments. SAE 1992 Transactions: Journal of Aerospace 1992; 101:448–57.
7. Schreiber BT, Lyon DR, Martin EL, et al. Impact of prior flight experience on learning Predator UAV operator skills. Mesa, AZ: Air Force Research Laboratory; 2002. Report No.: AFRL-HE-AZ-TR-2002–0026.
8. Tvaryanas AP. Visual scan patterns during simulated control of an uninhabited aerial vehicle. Aviat Space Environ Med 2004; 75:531–8.
9. Tvaryanas AP, Lopez N, Hickey P, et al. Effects of shift work and sustained operations: operator performance in remotely piloted aircraft (OP-REPAIR). Brooks City-Base, TX: United States Air Force, 311th Human Systems Wing; 2006. Report No.: HSW-PE-BR-TR-2006–0001.
10. Tvaryanas AP, Thompson WT. Fatigue in military aviation shift workers: survey results for selected occupational groups. Aviat Space Environ Med 2006; (in press).
11. Tvaryanas AP, Thompson WT, Constable SH. Human factors in remotely piloted aircraft operations: HFACS analysis of 221 mishaps over 10 years. Aviat Space Environ Med 2006; 77:724–32.
12. Tvaryanas AP, Thompson WT, Constable SH. The U.S. military unmanned aerial vehicle (UAV) experience: evidence-based human systems integration (HSI) lessons learned. NATO RTO Meeting Proceedings. Retrieved December 20, 2005 from: http://www.rta.nato. int/Pubs/RDP.asp?RDP=RTO-MP-HFM-124.
13. United States Air Force. The U.S. Air Force remotely piloted aircraft and unmanned aerial vehicle strategic vision. Retrieved July 17, 2006, from: http://www.uavforum.com/library/usaf_uav_strategic_vision.pdf
14. United States Air Force Scientific Advisory Board. Human systems integration in Air Force weapon systems development and acquisition. Washington, DC: Department of the Air Force, Department of Defense; 2004. Report No. SAB-TR-04–04.
15. Walters BA, Huber S, French J, Barnes MJ. Using simulation models to analyze the effects of crew size and crew fatigue on the control of tactical unmanned aerial vehicles (TUAVs). Aberdeen Proving Ground, MD: Army Research Laboratory; 2002. Report No.: ARL-CR-0483.
16. Weeks JL. Unmanned aerial vehicle operator qualifications. Mesa, AZ: Air Force Research Laboratories; 2000. Report No.: AFRL-HE-AZ-TR-2000–0002.
17. Wickens CD, Dixon S. Workload demands of remotely piloted vehicle supervision and control: single vehicle performance. Urbana-Champaign, IL: University of Illinois, Aviation Research Lab; 2002. Report No.: AHFD-02–10/MAD-02–1.
18. Williams KW. Unmanned aircraft pilot medical and certification requirements. Oklahoma City, OK: Civil Aerospace Medical Institute, Federal Aviation Administration. Retrieved February 25, 2006, from: http://www.hf.faa.gov/docs/508/docs/UAV05.pdf